On the Economic Distortions of Smoothing Aggregate Volatility with Monetary Policy

Adam B. Ashcraft *

JEL Codes: E52, E50, E52, E58

July 25, 2001

Abstract

Monetary policy is a blunt instrument with which to smooth aggregate volatility. I demonstrate that there is actually very little correlation between how much real state income responds to monetary policy and to shocks that prompt aggregate smoothing by the Federal Reserve. This mismatch turns out to be strong enough to imply that while monetary policy might have reduced the variance of aggregate output in the US over the last three decades, it has actually increased the variance of output in a majority of states. Moreover, policy rules that minimize aggregate variance are not equal in the severity of distortions they create in the volatility of state income. Optimal rules that place more weight on price variance typically create the largest distortions while those that place weight on aggregate income volatility create the smallest. In the end, monetary policy has the potential to create large distortions, but need not do so.

*Banking Studies Function, Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10029, (212) 720-1617, Adam.Ashcraft@ny.frb.org. Sincere thanks to Olivier Blanchard and Daron Acemoglu for their endless advice. Any remaining errors in this paper are my own, and the opinions expressed here do not necessarily reflect the views of the Federal Reserve Bank of New York or the Federal Reserve System.

1 Introduction

Monetary policy is the primary tool in advanced economies for smoothing business cycles. In the United States the central bank has been charged under the Federal Reserve Act with the objectives of maximum employment, stable prices, and moderate long-term interest rates. While the Federal Reserve has generally attempted to achieve these objectives by smoothing fluctuations in economic aggregates, it is possible that the aggregate economy is not the right unit of analysis when designing or evaluating monetary policy.

The aggregate economy is made up of potentially heterogeneous regions, each of which has its own response to the policy instrument and to the fluctuations that prompt aggregate smoothing by the central bank. When the correlation between how policy affects a region with how the shocks to be smoothed affect a region is low, a number of regions might not benefit very much – or may even suffer – under aggregate smoothing by the central bank. In this sense an exclusive focus by the central bank on economic aggregates might be inappropriate.

To fix ideas, consider an economy with two regions. Imagine a shock that affects the Eastern region and a policy instrument that largely operates through the Western region. Any aggregate smoothing of this shock increases volatility in the West and only affects the East indirectly through its linkages with the other region. The inability of the central bank to channel the impact of monetary policy in the affected region implies that aggregate smoothing actually weakly increases volatility in every region of the economy. [1] This is of course an extreme example, but does illustrate that there could be an important difference between smoothing aggregate and regional volatility. Developing evidence on the possible size of this difference is the primary task of this paper.

One might think that this issue is irrelevant in an economy as integrated as the United States. In the context of European integration, Frankel and Rose (1998) have argued that the large observed differences in the transmission mechanism of monetary policy across countries will become irrelevant as financial institutions converge over time. It's also likely that the free flow of goods and factors across borders facilitates the transmission of shocks across regions. On the other hand, integration could lead to specialization within regions that creates differences in industrial structure. [2] There is evidence that early monetary unions such at Italy, Germany, and the US have been correlated with increasing industrial specialization. [3] Differences in industrial structure alone could generate

[1] By creating a negative covariance between the two regions, volatility can actually increase in each region while aggregate volatility falls.

[2] See, for example, Dornbusch, Fischer, and Samuelson (1980).

[3] See Grauwe and Vanhevebeke (1994) and Krugman and Venables (1996).

differences in the transmission mechanism and in regional response to shocks.

Carlino and Defina (1998) have in fact documented that there are significant differences in the response of state income growth to changes in the federal funds rate and that much of the cross-sectional variation in this response is explained by differences in state industrial structure. The simple existence of variation across regions in the response to monetary policy is not enough by itself, however, to break the link between aggregate and regional smoothing. Differences in the response of regional output to policy may simply reflect differences in the sensitivity of regional output to the aggregate economy so that the smoothing of aggregate and regional volatility are one and the same. When either monetary policy or the shocks that monetary policy is smoothing have differential effects on regional growth directly, independent of any differences in the sensitivity to aggregate growth, there is no longer necessarily a connection between the smoothing of aggregate and regional volatility.

It turns out that there actually is very little correlation between how shocks that create aggregate volatility affect state output growth with how state output growth response to changes in monetary policy. This fact is illustrated in Figures (1) and (2), which plot the four quarter response of state income to the federal funds rate versus the response to an innovation in commodity prices or versus the response to an innovation in consumer confidence, respectively. [4] Commodity prices were chosen given their uncanny correlation with fluctuations while consumer confidence was chosen in accordance with a private theory of business cycles. It is clear the correlation between how state output growth responds to innovations in either consumer confidence or commodity prices with the response to monetary policy is nearly zero. [5]

This small correlation has important implications for when evaluating the performance of actual monetary policy over the last three decades. I demonstrate below that the estimated policy rule seems to have reduced the variance of aggregate output relative to policy of holding interest rates constant. On the other hand, the actual steady-state variance of output has increased for a majority of states representing at least half of the economy, implying that aggregate smoothing has largely been accomplished by generating negative a covariance in output across the states.

[4] The system includes the log of commodity prices, the federal funds rate, the log of aggregate income, the log of consumer prices, the consumer confidence index, and the log of income for U.S. states. This system is identified through the assumptions that the funds rate affects other variables only with a lag, confidence affects every variable except the funds rate with a lag, and commodity prices do not respond immediately to other variables. Moreover, I assume that state income depends only on aggregate variables and own lags so that spillovers across states are channeled through aggregate income.

[5] The correlation of state income response to the funds rate versus commodity price innovations is -0.02 while the correlation versus consumer confidence is 0.16. These difference persist at longer lags, being 0.08 and 0.15 after 8 quarters.

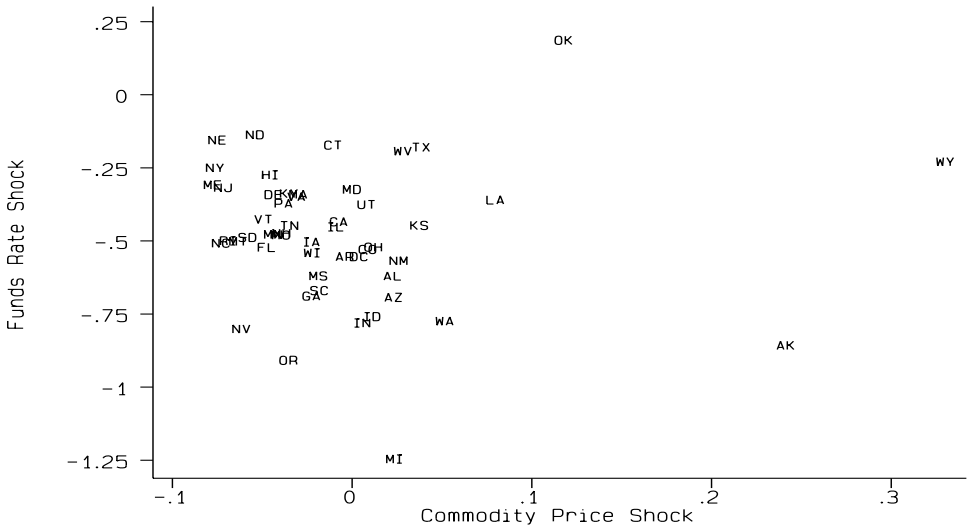

Figure 1: Response of State Income to Funds Rate versus Commodity Price Shock

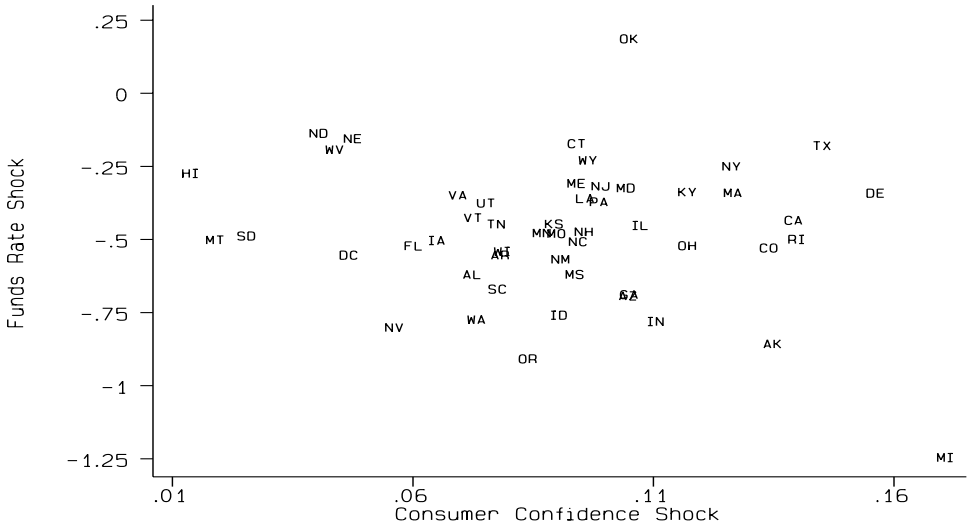

Figure 2: Response of State Income to Funds Rate versus Consumer Confidence Shock

When characterizing the set of policies that minimize the steady-state variance of prices and income, macroeconomists have generally found trade-offs between these two objectives. [6] Estimates of the policy rules actually used by the Federal Reserve have generally indicated that these rules are sub-optimal in the sense that the variance of both inflation and output growth could be reduced through a change in policy. As more recently estimated policy rules have seemed to move in this direction, it may seem like central bank performance is improving. [7] I demonstrate, however, that while a shift towards a Taylor rule for monetary policy would certainly reduce the variance of both aggregate output and prices, such a policy change continues to increase state volatility, although most often for states that represent a small fraction of the economy. All optimal rules are not equal in the severity of distortions they create, however, as those that place more weight on price volatility tend to increase the volatility of state income for a significant fraction of the economy.

Section 2 outlines the economic model and VAR estimation, while Section 3 outlines some reduced-form evidence. Section 4 characterizes the central bank's optimization problem and solution. Section 5 highlights results under the barest of assumptions, while Section 6 explores the robustness of these results in several dimensions.

2 Reduced-Form Evidence

The analysis below is going to require a great deal of structure on the data, so I am going to take a quick look at some correlations from a very reduced-form point of view to start. I first demonstrate there is a correlation between times when monetary policy is actively used and the dispersion of state income gaps, and then demonstrate that there is also a correlation between the time series volatility of state income gaps and the use of monetary policy. While I do not interpret either of these correlations as casual, they illustrate that the first-order correlations exist to back up the main message of this paper: monetary policy has the potential to create serious real distortions.

If the response of state income to monetary policy is as poorly correlated with the response to other types of shocks as was suggested above, it seems plausible that the use of monetary policy should increase the dispersion of state income. I look for this particular correlation in Table (1) through a regression of the quarterly state income gap, measured as state income growth minus its period mean, on current and lagged measures of the use of monetary policy since 1969. As

[6] For example, see Taylor (1979) and Defina, Stock, and Taylor (1996)

[7] Taylor (1993) illustrates that the federal funds rate in the 1980s closely tracked a simple optimal policy rule, while Taylor(1996) documents the mistakes of policy in the 1960s and 1970s.

both increases and decreases the funds rate should increase the dispersion, I use as a regressor alternatively the absolute value of changes in the funds rate and the squared change in the funds rate. In order to control for other time-series shocks that might be correlated with the use of monetary policy, I include current and lagged values of aggregate income growth. The table clearly indicates through positive coefficients on all lags of the funds rate that the use of monetary policy seems to increase the dispersion of state income gaps using either measure. F-tests for the joint significance of the monetary policy variables reject the hypothesis that they are zero at conventional significance levels.

That monetary policy increases the dispersion of income gaps is troubling, but would not be important if it was simply reducing the volatility of all state income gaps in an asymmetric manner. Estimating counterfactual income volatility is especially difficult without putting more structure on the data, but as a first-pass I split the sample into 16 eight-quarter time periods. Volatility is defined as the time-series standard deviation of the quarterly state income gap over each of these two-year time periods. I regress the time-series volatility of state income gaps on the measures of changes in monetary policy over the time period, using the sum of absolute value of the changes in the funds rate or the sum of squared changes in the funds rate alternatively. I control for a time trend and for aggregate income gap volatility. The table is clear, demonstrating that the use of monetary policy is correlated with higher volatility in state income gaps. I should restate that this should not be interpreted in a causal sense, as monetary policy could simply be used in times when state income volatility is high. These exercises are only suggestive, but indicate that the use of monetary policy is at least correlated with more disperse and more volatile state income gaps.

3 Model and Estimation

Consider an economy described by the economic variables z_t which include at first the log of aggregate income, the log of prices, and the log of income for each of 51 states. [8] The central bank has at its disposal one policy instrument x_t which will be either the federal funds rate in the spirit of Bernanke and Blinder (1992) or the log of money supply . I assume throughout this paper that these instruments cannot be used simultaneously as the primary mechanism though which the central bank exercises control over the funds rate – intervention in the reserves market – is the

[8] I understand that the District of Columbia is not, and will probably never be a state, but will refer to it as such for convenience.

Table 1: Monetary Policy and the Dispersion of State Output Gaps

	$\sqrt{V}(\Delta lnY_t^s)$	
X	$\lvert\Delta r_f\rvert$	$(\Delta r_f)^2$
X_t	0.0740	0.9400
	(0.0572)	(1.1807)
X_{t-1}	0.0153	0.1219
	(0.0457)	(0.8446)
X_{t-2}	0.0363	1.2436
	(0.0421)	(0.6220)
X_{t-3}	0.1122	2.3221
	(0.0284)	(0.3535)
X_{t-4}	0.0345	0.7365
	(0.0376)	(0.6777)
ΔlnY_t^a	-0.0907	-0.0937
	(0.0572)	(0.0569)
ΔlnY_{t-1}^a	-0.0117	-0.0289
	(0.0344)	(0.0389)
ΔlnY_{t-2}^a	0.0498	0.0372
	(0.0257)	(0.0268)
ΔlnY_{t-3}^a	0.0425	0.0326
	(0.0283)	(0.0243
ΔlnY_{t-4}^a	0.0041)	-0.0045
	(0.0364)	(0.0335
Constant	0.0086	0.0099
	(0.0005)	(0.0004)

Table Notes: The data include quarterly observations over 1969:1-1999:4. The table reports coefficents and standard errors from a regression of the cross-sectional standard deviation of state income gaps on current and lagged values of changes in monetary policy and aggregate income growth. The first column exploits the absolute value of changes in the funds rate while the second column uses the squared change in the funds rate.

Table 2: Monetary Policy and State Income Volatility

	$\sqrt{V}(\Delta lnY_t^s)$	
X	$\lvert\Delta r_f\rvert$	$(\Delta r_f)^2$
$\sqrt{V}(\Delta lnY_t^a)$	0.5749	0.5792
	(0.0377)	(0.0375)
X_t	0.0099	0.2749
	(0.0061)	(0.1344)
t	-0.0002	-0.0002
	(0.0001)	(0.0001)
Constant	0.0081	0.0085
	(0.0008)	(0.0006)

Table Notes: This analysis splits the sample period into 16 eight-quarter time periods, and each observation refers to a state during that time period. The table reports coefficents and white standard errors from a regression of the eight-quarter time-series standard deviation of state income gap on the eight-quarter standard deviation of aggregate income gap, measures of changes in monetary policy, and a time trend. The first column exploits the absolute value of changes in the funds rate while the second column uses the squared change in the funds rate.

same one through which it exerts pressure on the money supply. [9]

Volatility in non-policy variables is generated by a sequence of serially and mutually uncorrelated innovations v_t^z. For the analysis below I define Y_t as the vector of economic variables $\begin{pmatrix} z_t & x_t \end{pmatrix}'$ and v_t as the vector of shocks $\begin{pmatrix} v_t^z & v_t^x \end{pmatrix}'$. Innovations in policy v_t^x occur in practice, and are in fact necessary to identify the effect of policy on the economy, but should not occur when the optimal rule is employed. [10]

I assume that the economy has a linear structure, described by the following system of equations, [11]

[9] This is not strictly true in more recent years as banks' required reserves have fallen sharply over the last decade as banks have swept reservable deposits into non-reservable accounts overnight and banks' holdings of vault cash (which count towards required reserves) have increased greatly to stock ATMs. These developments have weakened control over the money supply considerably, but have not affected the ability of the Federal Reserve to control the funds rate.

[10] This ignores the well-studied problem of time-inconsistency in Kyland and Prescott (1977) and Calvo (1978). In a nutshell, the optimal policy rule can't be implemented because there are incentives to cheat at every point along the optimal path. Following Taylor (1979), the presumption here is that there is some mechanism through which policy-makers are able to commit to long-run objectives. The assumption of an infinite time horizon with no discounting in the loss function of the central bank below is consistent with this view.

[11] While the variables in this economy are written only as linear functions of current and lagged variables, this formulation is consistent with a model where agents have rational expectations as in Taylor (1979a). Expectations of future variables are predicted on the basis of current information that includes both current and past variables, imposing cross-equation restrictions on the coefficients. The presence of rational expectations is potentially important

$$Y_t = \pi_1 Y_{t-1} + \pi_2 Y_{t-2} + \pi_3 Y_{t-3} + \pi_4 Y_{t-4} + \gamma Y_t + v_t \tag{1}$$

where:

$$\gamma = \begin{bmatrix} \gamma_{zz} & \gamma_{zx} \\ \gamma_{xz} & \gamma_{xx} \end{bmatrix} \tag{2}$$

Note that the coefficient γ_{xx} as well as the diagonal elements of the submatrix γ_{zz} are zero. When invertible, this economy has the following quasi-reduced form representation,

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \phi_3 Y_{t-3} + \phi_4 Y_{t-4} + \phi_0 x_t + e_t \tag{3}$$

Without further restrictions on economic structure, there is correlation across equations in e_t as each of the reduced-form residuals is a linear function of all of the structural shocks. [12] While $Y_{t-1}...Y_{t-4}$ are predetermined variables, x_t is potentially endogenous due to a correlation with e_t. In order to identify ϕ_0, the immediate impact of monetary policy on non-policy variables, I follow Christiano, Eichenbaum and Evans (1996) with the assumption that monetary policy only affects non-policy variables with a lag but can react immediately to current non-policy variables. This assumption is convenient because it implies that the quasi-reduced form in equation (3) can be estimated directly by OLS. [13] Given consistent estimates of ϕ, the central bank can simply use equation (3) to trace out the future path of policy and non-policy variables in response to a vector of innovations e_t even without knowledge of the underlying structural parameters of the

when conducting counterfactual policy exercises like the ones implemented below. Sargent and Wallace (1975) argue that monetary policy is irrelevant when agents have rational expectations, while Taylor (1979b) shows that with fixed contracts and rational expectations monetary policy can have real effects.

[12] For those that are thinking too far ahead, the policy variable x_t is included in Y_t at this point only to estimate the actual policy rule used by the central bank over the sample period, and will be removed from the system below when formulating the optimal policy rule.

[13] If there was an underlying structural model of the economy complete with rational expectations, there would be restrictions across equations on the coefficients that could be exploited in estimation. While imposing these restrictions could improve efficiency over OLS if the model is correct, the estimator could be inconsistent if the underlying model is incorrect. This is of course the perfect environment in which to evaluate a structural model through a Hausman specification test. For some reason, the literature has avoided testing these restrictions. There is of course an unfortunate Catch-22 here. If these restrictions matter in the sense that the estimated parameters vary greatly from those estimated from OLS, the underlying structural model can be rejected. On the other hand, if the restrictions don't matter in this sense then OLS equation by equation is not such a bad thing to do and a structural model is unnecessary. While Taylor (1979a) imposes these cross-equation restrictions to impose rational expectations on the data, there is really no need to do so, and imposing these restrictions may yield biased estimates if exectations are not rational or the underlying macro model not specified correctly. Given the large costs of imposing potentially false restrictions on the data and the relatively small benefits of doing so, I prefer to ignore these restrictions and thus do not specify a structural model.

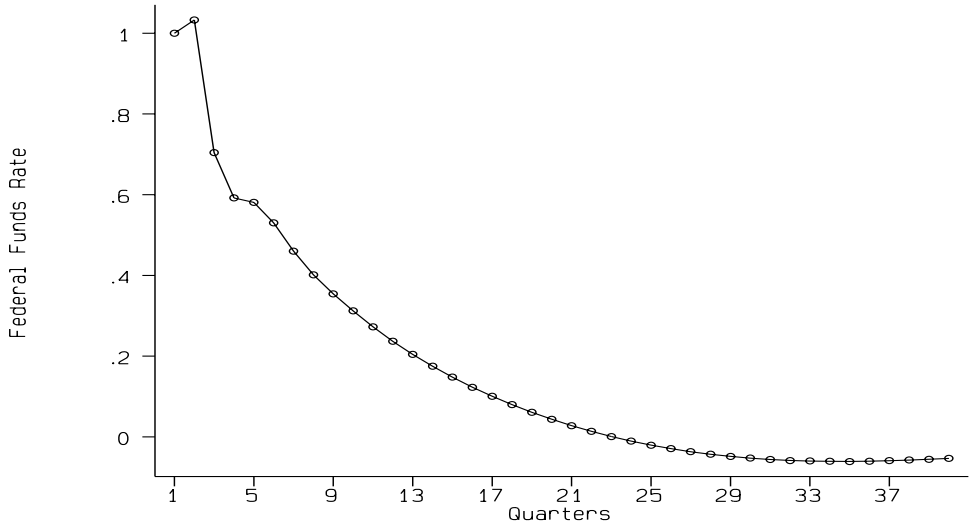

Figure 3: Response of Funds Rate to 100 Basis Point Funds Rate Innovation

economy. Note that this is a minor departure from existing research on optimal policy rules which typically identifies each of the structural equations in (1). I have only assumed that the central bank understands how monetary policy affects the economy, but does not have any other information about the structure of the economy, and thus cannot observe structural shocks v_t. Any additional knowledge of economic structure is largely irrelevant for the purposes of formulating optimal policy.

The first step is to estimate the quasi-reduced form system from equation (3) above using OLS. The estimation exploits quarterly data starting in 1969.1 through 1999.4. I use aggregate and state personal income provided by the Bureau of Economic Analysis deflated by the Consumer Price Index as a measure of real output. I also use a time series on the federal funds rate as an instrument of monetary policy, available from the Federal Reserve Bank of St. Louis. Finally, I use time series on the money stock measured by M1 from the Board of Governors of the Federal Reserve. Monthly data has been averaged by quarter, and none of the series have seasonally adjusted. Instead, I choose to include four quarterly dummies in each of the regressions below. The main data constraint is the availability of state personal income, which only goes back to the first quarter of 1969.

The baseline system of equations includes the federal funds rate, the log of aggregate real

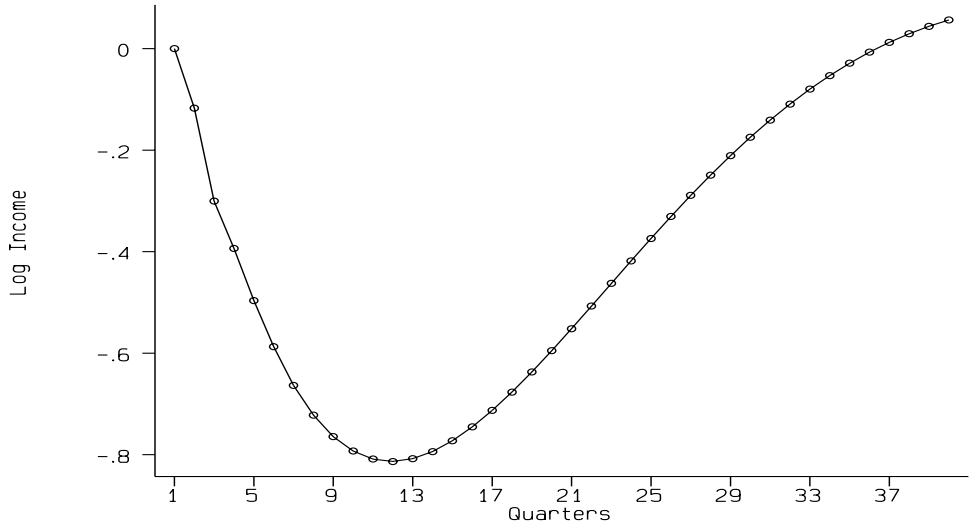

Figure 4: Response of Aggregate Income to 100 Basis Point Funds Rate Innovation

personal income, the log of prices, and the log of real personal income for 51 states. Without any restrictions it is not possible to estimate this system as there are more parameters than observations. When including four lags of each variable, each equation requires at least 216 parameters. I simplify this problem greatly through the assumption that aggregate variables are functions only of aggregate variables and that state variables are functions of aggregate variables and lags of only own state personal income. [14] In this formulation there is an equation for the funds rate that requires only 11 parameters (current and three lags of prices and aggregate income plus three lags of the funds rate) while the aggregate non-policy block requires 12 parameters (four lags of all aggregate variables). The state block requires 16 parameters per equation, with the additional parameters coming from the own lags on output growth.

I have performed unit root tests on each of the 54 variables included in this system, finding each one is integrated of order one and that log prices has two unit roots. Despite these unit roots, I choose to keep the system in levels to ensure monetary policy is neutral in the long run in the simplest manner possible. [15] I also use four lags of each variable in the system, finding that

[14] State income could depend on non-policy aggregate variables contemporaneously, but in transforming the system from (1) to (3) these variables do not appear in the estimating equation.

[15] Carlino and Defina (1998) have done most of their related work by taking appropriate differences, but permit

this is sufficient to eliminate any first-order serial correlation in the estimated residuals. I finally use the residuals of the estimated equations in order to estimate the covariance matrix V of u_t, imposing the identifying assumption that the innovation to monetary policy is uncorrelated with other residuals.

The response of the funds rate and aggregate income to a 100 basis point innovation is illustrated in Figures (3) and (4). The peak response on aggregate income is about 80 basis points after three years and monetary policy is neutral after about 10 years. Figure (5) illustrates the differences in how the funds rate affects state income over time. The aggregate response is displayed with the series of circles, and the response at each of the 50th, 25th, and 10th percentiles is illustrated by triangles, squares, and a line, respectively. What is striking about the figure is that states at or below the 25th percentile react very differently from other states. This monetary contraction has still reduced state income by 1 percent after 10 years at the 25th percentile while the effect at the 50th percentile then is basically zero. This is a crucial point which probably drives many of the results below.

4 Optimal Monetary Policy

The problem for the central bank is to choose a sequence for the policy variable that minimizes its loss function. In order to reduce the algebraic complexity of the optimization problem described below, it is convenient to re-write this system in first-order autoregressive form.

$$W_t = B * W_{t-1} + c * x_t + u_t \tag{4}$$

This is simply equation (3) stacked above a vector of equations requiring $Y_{t-j} = Y_{t-j}$ for $j = 1, 2, 3$. Under the assumption that monetary policy affects other variables with a lag the policy instrument x_t is either the lag of the funds rate or the log of lagged money supply. The coefficient matrix B consistent with this system has the following form,

monetary policy to have long-run effects on the real economy. I feel this is an unfair place to start in a paper trying to gauge the size of distortions created by monetary policy as the conventional prior is that policy is neutral I the long-run. Moreover, this differencing is not necessary for consistency of OLS, but may affect our ability to conduct inference. See Hamilton (1994) for a full discussion of this issue. The weakness of staying in levels is that it will not be possible to put confidence intervals on impulse responses, or standard errors on the steady-state statistics computed below.

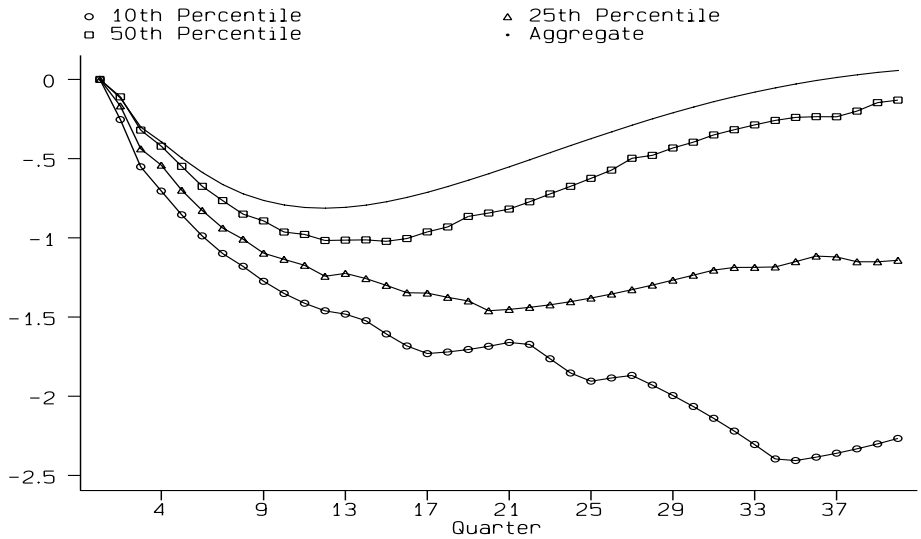

Figure 5: Response of State Income to 100 Basis Point Funds Rate Innovation

$$B = \begin{bmatrix} \phi_1 & \phi_2 & \phi_3 & \phi_4 \\ I & 0 & 0 & 0 \\ 0 & I & 0 & 0 \\ 0 & 0 & I & 0 \end{bmatrix} \tag{5}$$

Note that these coefficients in the first row can be partitioned into policy and non-policy components. The coefficients ϕ_j^{xz} and ϕ_j^{xx} described the actual policy rule above used by the central bank to choose instruments x_t. As we are interested in the behavior of non-policy variables under alternative policy rules, I remove the actual policy rule from the above system of equations. This is done by replacing each of $\begin{pmatrix} \phi_j^{xz} & \phi_j^{xx} \end{pmatrix}$ with a vector of zeros and ϕ_0^{zx} with the identity matrix. These replacements simply construct the equation $x_t = x_t$.

$$\phi_j = \begin{pmatrix} \phi_j^{zz} & \phi_j^{zx} \\ \phi_j^{xz} & \phi_j^{xx} \end{pmatrix} \text{ for } j = 1..4 \tag{6}$$

The vector W_t is simply the vector $\begin{pmatrix} Y_t & Y_{t-1} & Y_{t-2} & Y_{t-3} \end{pmatrix}'$ while the coefficient vector c con-

tains the elements $\begin{pmatrix}\phi_0 & 0 & 0 & 0\end{pmatrix}'$ and u_t is just the vector $\begin{pmatrix}e_t & 0 & 0 & 0\end{pmatrix}'$. In addition, any innovation to the policy rule is eliminated through the restriction $e_t^x = 0$, affecting the covariance matrix of e_t and thus u_t.

Optimal monetary policy by the central bank is described by the sequence of instruments x_t that minimize the central bank's loss function, described by the quadratic form below.

$$\min_{x_t}(W_t - W^*)'Q(W_t - W^*) \tag{7}$$

The vector W^* describes the central bank's target for each of the elements of W_t, while the matrix Q describes the bank's preferences over the autocovariances of the vector W_t. For a diagonal weighting matrix Q, the central bank is interested in minimizing the weighted variance of non-policy and/or policy variables around the target vector W^*. The solution to this problem is described in Chow (1975). Optimal policy is set as a function of lagged policy and non-policy variables.

$$x_t = GW_{t-1} + g \tag{8}$$

If a steady-state exists, the optimal policy rule converges as follows,

$$G = -(c'Hc)^{-1}c'HBH = Q + (B + cG)'H(B + cG) \tag{9}$$

In practice, given estimates of c and B this solution is derived through an initial guess for H (Q works fine), and iterating until G converges to steady-state.

Plugging this solution into the equation above describes the behavior of non-policy variables under optimal policy.

$$W_t = (B + cG)W_{t-1} + cg + u_t \tag{10}$$

Define the covariance matrix of u_t as $V = E[u_t u_t']$. The steady-state covariance matrix of W_t, defined here as $\Sigma = E[W_t W_t']$, is the solution to the following equation.

$$\Sigma = V + (B + cG)\Sigma(B + cG)' \tag{11}$$

In a manner similar to the above, given estimates of B, c, and V and the solution G above, the steady-state covariance is derived through an initial guess for Σ (V works fine) and iterating until

Σ converges. Note that the steady-state variance of W_t is independent of its mean, which will be W^*.

It is of course not only possible to describe the steady-state behavior of our economy under the optimal rule using equation, but actually to do so under any rule. For example, defining the vector G^a as $\begin{pmatrix} \phi_1^x & \phi_2^x & \phi_3^x & \phi_4^x \end{pmatrix}$, the steady-state variance of our economy following the actual policy rule would be the solution to this equation.

$$\Sigma_a = V + (B + cG^a)\Sigma_a(B + cG^a)' \tag{12}$$

Existing studies typically compare the actual variance of non-policy variables each the target vector W^*. [16] From equation (12), the steady-state variance of economic variables under the optimal policy clearly does not depend on the central bank's target W^* these variables. On the other hand, it is conventional to compare steady-state variance under the optimal policy to the actual variance of economic variables around the target W^*. This latter calculation obviously requires an assumption about the central bank's target. I find this approach unattractive as one could make very different conclusions about the performance of actual policy simply by using different assumptions about what the central bank's target might have been. [17]

Moreover, the actual variance of the economy is different from the steady-state variance of the economy under the actual policy rule for two reasons: innovations in the actual policy rule and any transition time to the new steady-state. This implies that even if the bank is following an optimal rule, the actual variance of the economy might be greater than the optimal variance. It thus seems appropriate to either compare the steady-state variances of the two policy rules or to simulate the actual variance of optimal policy given initial conditions over the sample period. In order to avoid having to make assumptions about central bank target variables, I choose to compare the steady-state variance of the economy across policy rules in the analysis below.

It is also possible to examine the implications of no feedback rules on steady-state variance by simply replacing G in equation (11) with a matrix of zeros. I also explore the implications of a random policy - where the steady-state variance of the policy instrument is equal to the steady-state variance of the instrument under the actual policy rule, but this variance is distributed randomly. This is done simply through appropriate adjustments to the diagonal elements of policy variables

[16] See Taylor (1979a, 1993) and Defina, Stock, and Taylor (1996).

[17] Taylor (1979a) found that a constant growth rate for the real money supply did not dominate actual policy (in terms of output growth and inflation variance), but admitted this result depended on the targets for output growth and inflation attributed to the central bank.

in the covariance matrix V of u_t. Under optimal policy these elements were of course set to zero as random innovations to the optimal policy rule are sub-optimal.

5 Results

I first consider the simple system described above using the federal funds rate as the instrument of monetary policy, then explore a more complicated economy in order to better control for omitted variables that could potentially bias our estimates.

5.1 Baseline Economy

Given estimates of the VAR from above, it is straightforward to use the equation (11) in order to compute the steady-state variance of each variable under the optimal policy rule. Table (3) summarizes the performance of our baseline economy under actual and naive rules for monetary policy. Panel (a) reports the steady-state standard deviation of the federal funds rate, log aggregate income, and the log price level when following the optimal and alternative policy rules. The first reports the steady-state standard deviation of these variables under the estimated policy rule with variance of innovations to this rule set to zero, while the second column simply inserts the estimated variance of estimated innovations into the covariance matrix of u. The final two columns illustrate the impact of two feedback rules, with a deterministic nominal funds rate in and a random funds rate (with variance equal to that under the actual policy rule), respectively.

The first interesting fact from the table is that monetary policy appears to have been somewhat successful in smoothing the volatility of aggregate output. This standard deviation under the actual policy rule without innovations falls by around 7-8 percent relative to deterministic and random rules and by only about 1-2 percent when including departures from the actual rule. This success appears to have been accomplished at the expense of higher price variance by around 12-25 percent depending on the counterfactual rule.

Given that actual policy appears to have reduced the variance of aggregate output relative to naive policy rules, it is natural to consider what has happened to state output in making a similar shift. This exercise is illustrated in panel (b) of Table (3). I construct the percentage change in steady-state standard deviation of state income from a shift in policy from a naive to actual rule. The first two columns report percentiles of the distribution of percentage changes corresponding to a shift from a deterministic rule to actual the policy rule with and without innovations, respectively.

A shift from a fixed to simple policy rule increased the standard deviation of state income by around 16 percent at the 90th percentile and reduced it by about 10 percent at the 10th percentile. The final two columns represent a similar shift, but from a random rule. Each of these exercises indicates that the benefits of aggregate smoothing have not been distributed equally among the states, usually increasing volatility in the median state. The final panel summarizes the magnitude of these asymmetries. The first row counts up the number of states that have greater volatility while the second row reports the share of these states in aggregate income. These numbers are extremely large, with much of the economy experiencing greater volatility. For the shift from a fixed rule to the actual rule without noise described above, 33 states representing almost three-fourths of the economy actually have greater volatility.

Table (4) summarizes optimal policy rules. Each of the first seven columns in the table vary the weight of aggregate income variance in a loss function that also a function of price variance, while the last column reports results for the actual policy rule without noise. As in the previous table, panel (a) describes the behavior of aggregate variables, indicating that there are generally trade-offs between the steady-state standard deviation of prices and aggregate output in the class of optimal policies. Moreover, actual policy lies far above the optimal frontier. Finally note that optimal policies ultimately work by increasing the steady-state standard deviation of the funds rate, and that the actual standard deviation is smaller than every point along the optimal policy frontier.

Panel (b) documents the percentiles of percentage change in standard deviation across states from the actual policy rule without noise to each point on the optimal frontier. The first two rows of panel (c) report statistics similar to the table above on the number of states having higher volatility and their share in aggregate income. A move from actual policy toward optimal policy with equal weights on the variance of prices and aggregate output could reduce the standard deviation of output by almost 30 percent, but such a shift increases volatility by almost 30 percent at the 90th percentile in the distribution of states. The bottom panel reports statistics similar to the previous table, demonstrating that even in the best of cases such a transition involves increasing the output volatility of at least a dozen states representing at one-fourth of the economy.

5.2 Another Weighting Matrix

One might be concerned that there are differences between the variance of aggregate income and the variance of aggregate income implied by the variances and covariances of state income. In order

to ensure the consistency of the central bank's preferences, I complicate the objective function, recognizing the presence of both aggregate and state income in the vector W_t. In order to ensure preferences are consistent, I impose additional restrictions on the form of Q. Note that the change in log of aggregate income can be written as a weighted sum of the change in log of state income.

$$\Delta \ln Y_t^a = \theta' \Delta \ln Y_t^s \tag{13}$$

The vector θ corresponds to the state share of aggregate income while the vector ΔlnY_t^s corresponds to state output growth. For simplicity, I assume that this share is constant, and write the variance of aggregate output growth as a quadratic form in state output growth and a matrix of state output shares θ. As our system above is written in levels, we need an identity relating the log of aggregate income to the log of state income. To accomplish this I write the difference in logs relative to a base year so that $\Delta \ln Y_t^s = \ln Y_t^s - \ln Y_0^s$ and $\Delta \ln Y_t^a = \ln Y_t^a - \ln Y_0^a$. This normalization permits the above equation to be rewritten as,

$$\ln Y_t^a = \ln Y_0^a - \theta' \ln Y_0^s + \theta' \ln Y_t^s \tag{14}$$

In a time-series sense, the first two terms on the right-hand side of this equation are constant, which will disappear when writing the variance of the log of aggregate income as an income-share-weighted sum of the variances and covariances of state income.

$$V(\Delta lnY_t^a) = E[(\Delta lnY_t^s)'\theta\theta'(\Delta lnY_t^s)] \tag{15}$$

It follows that the upper left block of Q must have the following form with a weight of α on the variance of aggregate growth.

$$Q_1 = \begin{bmatrix} \frac{1}{2}\alpha & 0 & 0 & 0 \\ 0 & \frac{1}{2}\alpha\theta\theta' & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{16}$$

One should note that the optimal policy rule could be quite complex given the number of variables in the system. In what follows, even though aggregate variables are unaffected by state variables in the VAR, the optimal policy rule will generally be a function of both aggregate and state variables when using this weighting matrix.

It turns out that results are no different from those in the previous table, implying that there is no difference between the actual and implied aggregate variance in the exercises above.

5.3 A Larger VAR

One potentially serious problem with the estimation strategy above the presence of important omitted variables in the system above. As the dynamic response of aggregate and state income to policy generally depends on all of the parameters in the system, a bias created by omitted variables for any one parameter could radically change the conclusions above. In fact, it is well-known that the absence of commodity prices from the above system biases the response of prices to monetary policy such that a monetary contraction actually increases prices. This is one important reason to expand the system.

I simply add commodity prices and consumer confidence to the system above, making only the assumption that confidence and commodity price shocks respond to policy only with a lag. While this seems natural for commodity prices that are determined in large international markets, consumer confidence is in part based on expectations of the future. Changes in the stance of monetary policy plausibly affect those expectations, and could in principle have an immediate effect on confidence through this mechanism. In practice, however, I am skeptical that innovations in the policy rule have much of a direct impact on consumer spending decisions.

I exploit the producer price index for fuel, related products, and power as a measure of commodity prices and the University of Michigan Survey of Consumer Sentiment as a measure of consumer confidence. Both of these series are available on-line at the Federal Reserve Bank of St. Louis. I also choose to use the weighting matrix described in the previous section to ensure that the implied aggregate volatility of state income matches actual aggregate volatility.

Table (5) describes the steady-state performance of our new economy. Little has changed qualitatively from before, as policy continues to reduce the volatility of aggregate income and increase the volatility of prices and interest rates. What is new is that actual policy has greatly increased volatility in consumer confidence and commodity prices. The lower panel of the table illustrates that the asymmetric impact of this aggregate smoothing appears to be much smaller after expanding the VAR by two variables. At its worst actual policy increases the volatility of income for 30 states representing about half of aggregate income, down from 44 states representing over 90 percent of income above. Note the significant differences between the actual policy rule with and without noise, however. The implication here is that innovations in the policy rule have

actually reduced aggregate performance and exacerbated the distortions of policy relative to naive policy rules.

The optimal policy rule is characterized in this new economy in Table (6). As above, each of the first seven columns corresponds to different weights of aggregate income in the weighting matrix, with the final column representing the actual policy rule without noise. There are again trade-offs between income and price variance, but the second-order Phillips curve is much flatter in (income-price volatility space). The bottom panel confirms what the previous table hinted at – that the distortions across states of aggregate smoothing are much smaller than measured above. A transition from the actual rule without noise to eliminating all of the volatility possible in aggregate income would reduce the standard deviation of aggregate income by two-thirds, but would still increase volatility in eight states representing just under 5 percent of aggregate income.

An interesting point on the optimal frontier exists where the central bank weights output volatility by 10 percent. A shift from the actual policy rule without noise would still reduce the steady-state standard deviation of income by around one-third with a small reduction in price volatility, but such a policy would actually increase income volatility for a majority of states representing almost one-third of aggregate income. This underscores an important result that appeared in each of the tables above: the distortions in state income volatility created by a shift from actual policy to Taylor rules that only improve aggregate performance will increase as the central bank substitutes a reduction in income volatility for price volatility. This is an important empirical fact given the recent observations by Boivin and Giannoni (2001) that the Federal Reserve appears to have increased the sensitivity of the funds rate to prices over the last 15 years relative to prior policy.

6 Conclusions

So what does this all mean? First, any success that the Federal Reserve has had in reducing aggregate volatility should now be qualified, as it has actually increased volatility for a majority of states representing at least half of aggregate income. Second, it seems possible to design monetary policy to achieve aggregate targets with relatively small distortions, but it is not clear whether or not policy is moving in that direction. Finally, if the main policy instrument used by the central bank has significant imperfections, one might start to ponder if there are alternative or secondary instruments that could meet targets for full employment and price stability at an aggregate and state level. In particular, perhaps through more active use of the discount window at regional banks

or by including municipal bonds in open market operations the central bank could more effectively channel demand shocks to the regions that need them the most. In any case, it is a bit troubling that in an economy as integrated as the United States monetary policy has the capacity to create such large distortions, and is an important lesson for countries around the world pondering the costs and benefits of monetary union.

References

[1] Blanchard, Olivier and Quah, Denny (1988), "The Dynamic Effects of Aggregate Demand and Supply Disturbances," Working Paper Number 2737, National Bureau of Economic Research.

[2] Boivin, Jean and Giannoni, Marc (2001), The Monetary Transmission Mechanism: Has it Changed?" unpublished Working Paper.

[3] Calvo, Guillermo (1978), "On the Time Consistency of Optimal Policy in a Monetary Economy," Econometrica, Volume 46, Issue 6.

[4] Carlino, Gerald A. and DeFina, Robert (1998), "The Differential Regional Effects of Monetary Policy," Review of Economics and Statistics.

[5] Christiano, Lawrence J., Eichenbaum, Martin and Evans, Charles (1998), "Monetary Policy Shocks: What Have We Learned and to What End?" Working Paper Number 6400, National Bureau of Economic Research.

[6] Chow, Gregory C. (1970), "Optimal Stochastic Control of Linear Economic Systems," Journal of Money, Credit, and Banking, Volume 2, Issue 3, pp. 291-302.

[7] DeFina, Robert H., Stark, Thomas C., and Taylor, Herbert E. (1996), "The Long-Run Variance of Output and Inflation under Alternative Monetary Policy Rules," The Journal of Macroeconomics, pp. 235-251.

[8] Dornbusch, Rudi, Fischer, Stanley and Samuelson, Paul (1980), "Hecksher-Olin Theory with a Continuum of Goods," The Quarterly Journal of Economics.

[9] Frankel, Jeffrey and Rose (1988)

[10] Grauwe and Vanhavebeke (1994), "Is Europe an Optimal Currency Area? Evidence from Regional Data." Masson, Paul R and Taylor, Mark P., eds. Policy issues in the operation of currency unions. Cambridge; New York and Melbourne: Cambridge University Press, 1993, pages 111-29.

[11] Hallett, Andrew H. and Piscitelli, Laura (1999), "EMU in Reality: The Effect of a Common Monetary Policy on Economies with Different Transmission Mechanisms," Empirica, Volume 26, pp. 337-358.

[12] Hamilton, James (1994), *Time Series Analysis,* Princeton, NJ: Princeton University Press.

[13] Krugman, Paul and Venables (1996), "Integration, Specialization, and Adjustment," European Economic Review, Volume 40 (3-5), pp. 959-967.

[14] Kyland, Finn E. and Prescott, Edward C. (1977), "Rules Rather than Discretion: The Inconsistency of Optimal Plans," The Journal of Political Economy, Volume 83, pp. 1009-21.

[15] Poole, William (1970), The Quarterly Journal of Economics, Issue 2, pp. 197-216.

[16] Sargent, Thomas J. and Wallace, Neil (1975), "Rational Expectations, the Optimal Monetary Instrument, and the Optimal Money Supply Rule," Journal of Political Economy, Volume 83, no. 2.

[17] Sims, Christopher A. and Zha, Tao (1996), "Does Monetary Policy Generate Recessions?" unpublished Working Paper.

[18] Taylor, John (1979), "Estimation and Control of a Macroeconomic Model with Rational Expectations," Econometrica, Volume 47, Issue 5, pp. 1267-1286.

[19] Taylor, John (1993), "Discretion Versus Policy Rules in Practice," Carnegie-Rochester Conference Series in Public Policy, Volume 39, pp. 195-214.

[20] Taylor, John (1998), "An Historical Analysis of Monetary Policy Rules," Working Paper Number 6768, National Bureau of Economic Research.

Table 3: Performance of the Baseline Economy

A. Standard Deviation of Aggregate Income				
	Actual Policy		Naive Policy	
	Simple	+ Noise	None	Random
R_f	0.55	1.16	0.00	0.55
$\ln(Y^a)$	1.00	1.02	1.01	1.02
$\ln(P)$	0.41	0.41	0.34	0.35

B. Percentiles of the Percentage Change in Standard Deviation of State Income				
To	Actual: Simple		Actual: + Noise	
From	None	Random	None	Random
90th	4.01	2.59	8.36	6.02
75th	1.70	0.58	4.99	3.52
50th	0.36	-0.43	2.30	1.38
25th	-1.96	-3.17	0.38	-0.56
10th	-3.72	-4.98	-1.38	-2.33
Worse	29	19	40	36
Share	59.98	31.17	73.23	66.12

Table Notes: Panel (a) of the table reports the steady-state standard deviation of the funds rate, aggregate income, and price level under actual and naive policies. The first column uses only the estimated policy rule while the second column adds the variance of innovations to this rule. The third column is a policy of smoothing volatiilty in the funds rate while the fourth column is a policy of changing the funds rate randomly with standard deviation equal to that implied by the actual rule without noise. Panel (b) describes the percentiles of the percentage change in steady-state standard deviation in state income created by a change in policy. The first two columns describe a shift from each naive policy to the actual rule without innovations, while the latter two columns describe a shift to the actual rule with estimated noise. The bottom panel describes the number of states that actually have increased volatility in response to such a policy shift and the share that these states have in aggregate income.

Table 4: Optimal Performance of the Baseline Economy

	Optimal Rule (weight on income)							Actual
	0	10	25	50	75	90	100	Simple
R_f	0.74	0.73	0.80	0.96	1.04	1.11	1.12	0.55
$\ln(Y^a)$	0.97	0.94	0.92	0.91	0.91	0.90	0.90	1.00
$\ln(P)$	0.26	0.26	0.27	0.28	0.30	0.31	0.31	0.41

Percentages of the Percentage Change in Standard Deviation of State Income								
From	Simple	Simple	Simple	Simple	Simple	Simple	Simple	
To	0	10	25	50	75	90	100	
From	Simple	Simple	Simple	Simple	Simple	Simple	Simple	
90th	3.30	1.22	0.16	0.22	0.17	0.20	0.21	
75th	1.12	0.08	-0.89	-1.56	-1.58	-1.08	-1.09	
50th	-1.77	-3.28	-4.52	-4.88	-5.10	-5.16	-5.17	
25th	-4.66	-6.60	-7.47	-7.65	-7.52	-7.21	-6.99	
10th	-6.12	-7.97	-8.95	-8.99	-9.25	-9.17	-9.10	
Worse	20	14	8	6	6	6	6	29
Share	22.56	9.39	6.18	3.89	12.88	12.88	12.88	

Table Notes: The top panel of the table reports the steady-state standard deviation of the funds rate, aggregate income, and price level under actual and naive policies. The first column corresponds to a weight of 100 percent on the volatility of prices in the central bank's loss function, and this weight declines to 0 percent in the next six columns. The bottom panel describes the percentiles of the percentage change in steady-state standard deviation in state income created by a change in policy from the actual rule without noise to each of the optimal policies described in the top panel. The bottom panel describes the number of states that actually have increased volatility in response to such a policy shift and the share that these states have in aggregate income.

Table 5: Performance of the Full Economy

A. Standard Deviation of Aggregate Income				
	Actual Policy		Naive Policy	
	Simple	+ Noise	None	Random
R_f	0.69	1.17	0.00	0.69
$\ln(Y^a)$	0.97	0.99	1.01	1.03
$\ln(P)$	0.43	0.44	0.33	0.34
$\ln(P^c)$	2.23	2.25	2.06	2.09
CC	4.83	4.95	4.72	4.80

B. Percentiles of the Percentage Change in Standard Deviation of State Income				
To	Actual: Simple		Actual: + Noise	
From	None	Random	None	Random
90th	7.41	5.52	10.76	7.46
75th	4.78	3.09	6.92	5.19
50th	2.07	0.63	4.02	2.04
25th	-1.04	-2.31	0.72	-1.14
10th	-3.19	-4.83	-1.13	-3.11
Worse	36	29	40	6
Share	70.24	65.65	73.77	70.24

Table Notes: Panel (a) of the table reports the steady-state standard deviation of the funds rate, aggregate income, and price level under actual and naive policies. The first column uses only the estimated policy rule while the second column adds the variance of innovations to this rule. The third column is a policy of smoothing volatility in the funds rate while the fourth column is a policy of changing the funds rate randomly with standard deviation equal to that implied by the actual rule without noise. Panel (b) describes the percentiles of the percentage change in steady-state standard deviation in state income created by a change in policy. The first two columns describe a shift from each naive policy to the actual rule without innovations, while the latter two columns describe a shift to the actual rule with estimated noise. The bottom panel describes the number of states that actually have increased volatility in response to such a policy shift and the share that these states have in aggregate income.

Table 6: Optimal Performance of the Full Economy

	Optimal (weight on income)							Actual
	0	10	25	50	75	90	100	Simple
R_f	0.74	0.73	0.82	0.99	1.37	1.20	1.26	0.69
$\ln(Y^a)$	1.05	0.96	0.91	0.89	0.88	0.88	0.88	1.03
$\ln(P)$	0.25	0.26	0.28	0.31	0.32	0.33	0.33	0.34
$\ln(P^c)$	2.00	1.93	1.92	1.95	1.99	1.99	2.01	2.09
CC	4.86	4.79	4.81	4.89	4.97	5.01	5.05	4.80

Percentages of the Percentage Change in Standard Deviation of State Income								
To	0	10	25	50	75	90	100	
From	Simple	Simple	Simple	Simple	Simple	Simple	Simple	
90th	8.30	2.62	0.89	1.18	5.50	1.39	1.77	
75th	3.34	-0.29	-2.00	-2.37	-0.70	-2.13	-1.96	
50th	-1.44	-4.23	-5.33	-6.04	-5.75	-5.56	-5.45	
25th	-5.40	-9.37	-10.59	-10.62	-9.32	-9.51	-9.38	
10th	-9.72	-12.59	-13.81	-13.52	-12.02	-12.62	-12.30	
Worse	22	13	7	6	12	8	9	36
Share	36.47	25.27	15.85	15.54	21.81	16.35	17.53	

Table Notes: The top panel of the table reports the steady-state standard deviation of the funds rate, aggregate income, and price level under actual and naive policies. The first column corresponds to a weight of 100 percent on the volatility of prices in the central bank's loss function, and this weight declines to 0 percent in the next six columns. The bottom panel describes the percentiles of the percentage change in steady-state standard deviation in state income created by a change in policy from the actual rule without noise to each of the optimal policies described in the top panel. The bottom panel describes the number of states that actually have increased volatility in response to such a policy shift and the share that these states have in aggregate income.